Arvind Borde / PHY 11, Week 4: Dynamics and Newton's Laws

(1) A ball is rolling down the road at a constant velocity. Does it need a force acting on it to keep it moving at the same velocity? __________

(2) A rocket is moving at a constant velocity. Does it need a force acting on it to keep it moving at the same velocity? __________

(3) What is different about the two situations?

1 ______________________________________

(4) A hockey puck of the same mass as the ball from Q1 is skidding on the ice at the same velocity as the ball. Does it need more force acting on it than the ball did, less, or the same to keep its velocity fixed? __________

(5) Why? ______________________

(6) What is the moral of this story? __________

2 ______________________________________

(7) If an object is at rest, can it start to move spontaneously without forces acting in it?

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(8) Who's this?

(9) OK, you decide to collide with Dr. Hulk* . . .

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(10) Will you feel a force acting on you at the moment of collision? __________

(11) Will the Hulk feel a force acting on him at the moment of collision? __________

(12) Will the force on you be the same as that on the Hulk, bigger, or less? ____________

(13) If both of you recoil from the collision, who will recoil more? __________

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It's time to summarize all the wisdom we've gained.

But before that, a blast from the past. . .

(14) For a boost to an A in the course, in 3 seconds, what was the most important thing you learned in week 2? ______________________

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6 Keep this in mind.

ADDITIONAL NOTES

Newton's Laws of Motion

▷ **Law 1**: ______________________________

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We'll abbreviate Newton's First Law as "NFL."

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(15) Your car crashes into a lamppost. You're not wearing a seatbelt and you smash through the windshield. Who do you blame?

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(16) Your car crashed into the lamppost because you decided it would be fun to press on the gas and accelerate toward it. You had a beverage cup on the dashboard containing a clear liquid. Let's call it "water". What does the cup do as you hit the gas.

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(17) So, an object initially at rest suddenly starts moving toward you. NFL says objects cannot move unless a force acts on it. But there's no backward force on the cup. What gives?

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Newton's Laws hold in a class of reference frames called ______________. Inertial frames move with uniform velocity relative to each other.

Once you have one, you can find them all. ______________________________.

If you know all the forces in a situation, then NFL can be used to define an inertial frame. But you may not know all the forces.

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▷ **Law 2**: ______________________________

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In equation form, if $\vec{F} = \sum \vec{F}_i$ is the total force on an object of mass m, then

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ADDITIONAL NOTES

This is a ______________ equation and can be broken into components. In 3d:

The mass in NSL is a measure of its _______ – its tendency to resist forces.

13

(18) You push a piece of chalk with your finger, then push your car with the same force. Which moves more in response? __________________

(19) Why? _________________________________ ______________

In $$\vec{F} = m\vec{a}$$
if the force is fixed, the smaller the mass the greater the response to the force (acceleration).

14

NSL says something very important conceptually:

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An object needs no forces to keep it moving with uniform (steady) velocity, but it does need a force to make it accelerate.

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Units

▷ SI system: distance in meters (m), mass in kilograms (kg), time in seconds (s).

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One Newton is the force required to produce an acceleration of $1\,\mathrm{m/s^2}$ in a mass of $1\,\mathrm{kg}$.

16

▷ cgs system: distance in centimeters (cm), mass in grams (g), time in seconds (s).

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One dyne is the force required to produce an acceleration of $1\,\mathrm{cm/s^2}$ in a mass of $1\,\mathrm{g}$.

17

▷ British system: distance in feet (ft), mass in slugs (slug), time in seconds (s).

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One dyne is the force required to produce an acceleration of $1\,\mathrm{ft/s^2}$ in a mass of $1\,\mathrm{slug}$.

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ADDITIONAL NOTES

(20) We have

$$1\,\mathrm{N} = 1\,\mathrm{kg{\cdot}m/s^2} \text{ and } 1\,\mathrm{dyne} = 1\,\mathrm{g{\cdot}cm/s^2}$$

What is 1 Newton in dynes?

19

EXAMPLE 4–2 | ESTIMATE **Force to accelerate a fast car.** Estimate the net force needed to accelerate (*a*) a 1000-kg car at $\frac{1}{2}g$; (*b*) a 200-gram apple at the same rate.

APPROACH We use Newton's second law to find the net force needed for each object; we are given the mass and the acceleration. This is an estimate (the $\frac{1}{2}$ is not said to be precise) so we round off to one significant figure.

SOLUTION (*a*) The car's acceleration is $a = \frac{1}{2}g = \frac{1}{2}(9.8\,\mathrm{m/s^2}) \approx 5\,\mathrm{m/s^2}$. We use Newton's second law to get the net force needed to achieve this acceleration:

$$\Sigma F = ma \approx (1000\,\mathrm{kg})(5\,\mathrm{m/s^2}) = 5000\,\mathrm{N}.$$

(If you are used to British units, to get an idea of what a 5000-N force is, you can divide by 4.45 N/lb and get a force of about 1000 lb.)

(*b*) For the apple, $m = 200\,\mathrm{g} = 0.2\,\mathrm{kg}$, so

$$\Sigma F = ma \approx (0.2\,\mathrm{kg})(5\,\mathrm{m/s^2}) = 1\,\mathrm{N}.$$

20

EXAMPLE 4–3 **Force to stop a car.** What average net force is required to bring a 1500-kg car to rest from a speed of 100 km/h within a distance of 55 m?

APPROACH We use Newton's second law, $\Sigma F = ma$, to determine the force, but first we need to calculate the acceleration a. We assume the acceleration is constant so that we can use the kinematic equations, Eqs. 2–11, to calculate it.

FIGURE 4–6 Example 4–3.

21

SOLUTION We assume the motion is along the $+x$ axis (Fig. 4–6). We are given the initial velocity $v_0 = 100\,\mathrm{km/h} = 27.8\,\mathrm{m/s}$ (Section 1–6), the final velocity $v = 0$, and the distance traveled $x - x_0 = 55\,\mathrm{m}$. From Eq. 2–11c, we have

$$v^2 = v_0^2 + 2a(x - x_0),$$

so

$$a = \frac{v^2 - v_0^2}{2(x - x_0)} = \frac{0 - (27.8\,\mathrm{m/s})^2}{2(55\,\mathrm{m})} = -7.0\,\mathrm{m/s^2}.$$

The net force required is then

$$\Sigma F = ma = (1500\,\mathrm{kg})(-7.0\,\mathrm{m/s^2}) = -1.1 \times 10^4\,\mathrm{N},$$

or 11,000 N. The force must be exerted in the direction *opposite* to the initial velocity, which is what the negative sign means.

22

▷ **Law 3**: ____

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(21) Explain why in the Hulk-you collision, (a) you both feel the same forces, but (b) you recoil more.

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ADDITIONAL NOTES

(22) What makes a rocket move? ________

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(23) What makes a jet plane move? ________

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(24) What makes a propeller plane move? ______

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(25) What makes a car move? ______

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(26) What allows you to walk? ______

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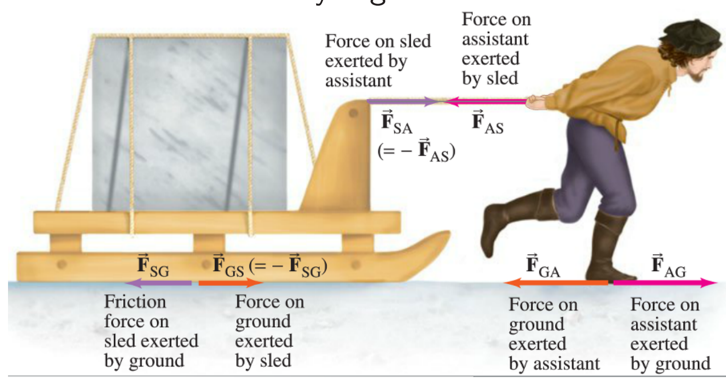
Analyzing Forces



28

The Gravitational Force

The earth exerts a downward force on all of us (points to center of earth). We'll study a formula for it later, but the force produces an acceleration, which we'll call $\vec{g}$, with magnitude g:

$$g = 9.8\,\mathrm{m/s^2}.$$

(Do not confuse g with g (gram). Context and typeface will indicate which is meant.)

29

Weight vs Mass

Your mass is a measure of your inertia, your resistance to force. Expressed in units of mass.

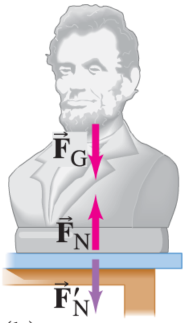
Your weight on earth is a measure of the earth's gravitational force on you. Expressed in units of force.

If you go to the moon your mass does not change, but your weight does.

30

ADDITIONAL NOTES

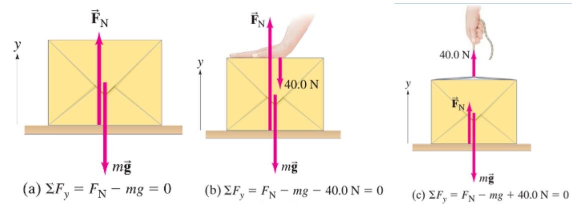
Normal (Perpendicular) Forces



(27) Why doesn't Abe move?

31

EXAMPLE 4–6 **Weight, normal force, and a box.** A friend has given you a special gift, a box of mass 10.0 kg with a mystery surprise inside. The box is resting on the smooth (frictionless) horizontal surface of a table (Fig. 4–15a). (*a*) Determine the weight of the box and the normal force exerted on it by the table. (*b*) Now your friend pushes down on the box with a force of 40.0 N, as in Fig. 4–15b. Again determine the normal force exerted on the box by the table. (*c*) If your friend pulls upward on the box with a force of 40.0 N (Fig. 4–15c), what now is the normal force exerted on the box by the table?



(a) $\Sigma F_y = F_N - mg = 0$ (b) $\Sigma F_y = F_N - mg - 40.0\,\text{N} = 0$ (c) $\Sigma F_y = F_N - mg + 40.0\,\text{N} = 0$

32

SOLUTION (*a*) The weight of the box is $mg = (10.0\,\text{kg})(9.80\,\text{m/s}^2) = 98.0\,\text{N}$, and this force acts downward. The only other force on the box is the normal force exerted upward on it by the table, as shown in Fig. 4–15a. We chose the upward direction as the positive y direction; then the net force ΣF_y on the box is $\Sigma F_y = F_N - mg$; the minus sign means mg acts in the negative y direction (m and g are magnitudes). The box is at rest, so the net force on it must be zero (Newton's second law, $\Sigma F_y = ma_y$, and $a_y = 0$). Thus

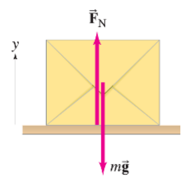
$$\begin{aligned}\Sigma F_y &= ma_y\\ F_N - mg &= 0,\end{aligned}$$

so we have

$$F_N = mg.$$

The normal force on the box, exerted by the table, is 98.0 N upward, and has magnitude equal to the box's weight.

33



(a) $\Sigma F_y = F_N - mg = 0$

34

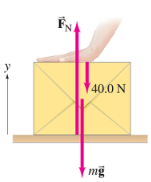
(*b*) Your friend is pushing down on the box with a force of 40.0 N. So instead of only two forces acting on the box, now there are three forces acting on the box, as shown in Fig. 4–15b. The weight of the box is still $mg = 98.0\,\text{N}$. The net force is $\Sigma F_y = F_N - mg - 40.0\,\text{N}$, and is equal to zero because the box remains at rest $(a = 0)$. Newton's second law gives

$$\Sigma F_y = F_N - mg - 40.0\,\text{N} = 0.$$

We solve this equation for the normal force:

$$F_N = mg + 40.0\,\text{N} = 98.0\,\text{N} + 40.0\,\text{N} = 138.0\,\text{N},$$

which is greater than in (*a*). The table pushes back with more force when a person pushes down on the box. The normal force is not always equal to the weight!



35

(b) $\Sigma F_y = F_N - mg - 40.0\,\text{N} = 0$

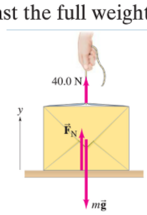
(*c*) The box's weight is still 98.0 N and acts downward. The force exerted by your friend and the normal force both act upward (positive direction), as shown in Fig. 4–15c. The box doesn't move since your friend's upward force is less than the weight. The net force, again set to zero in Newton's second law because $a = 0$, is

$$\Sigma F_y = F_N - mg + 40.0\,\text{N} = 0,$$

so

$$F_N = mg - 40.0\,\text{N} = 98.0\,\text{N} - 40.0\,\text{N} = 58.0\,\text{N}.$$

The table does not push against the full weight of the box because of the upward force exerted by your friend.

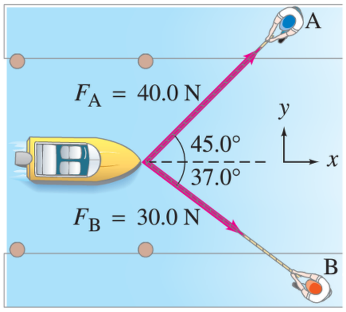


(c) $\Sigma F_y = F_N - mg + 40.0\,\text{N} = 0$

36

ADDITIONAL NOTES

EXAMPLE 4–9 **Adding force vectors.** Calculate the sum of the two forces exerted on the boat by workers A and B in Fig. 4–19a.



37

SOLUTION The two force vectors are shown resolved into components in Fig. 4–19b. We add the forces using the method of components. The components of $\vec{\mathbf{F}}_A$ are

$$F_{Ax} = F_A \cos 45.0° = (40.0\,\text{N})(0.707) = 28.3\,\text{N},$$
$$F_{Ay} = F_A \sin 45.0° = (40.0\,\text{N})(0.707) = 28.3\,\text{N}.$$

The components of $\vec{\mathbf{F}}_B$ are

$$F_{Bx} = +F_B \cos 37.0° = +(30.0\,\text{N})(0.799) = +24.0\,\text{N},$$
$$F_{By} = -F_B \sin 37.0° = -(30.0\,\text{N})(0.602) = -18.1\,\text{N}.$$

F_{By} is negative because it points along the negative y axis. The components of the resultant force are (see Fig. 4–19c)

38

$$F_{Rx} = F_{Ax} + F_{Bx} = 28.3\,\text{N} + 24.0\,\text{N} = 52.3\,\text{N},$$
$$F_{Ry} = F_{Ay} + F_{By} = 28.3\,\text{N} - 18.1\,\text{N} = 10.2\,\text{N}.$$

To find the magnitude of the resultant force, we use the Pythagorean theorem,

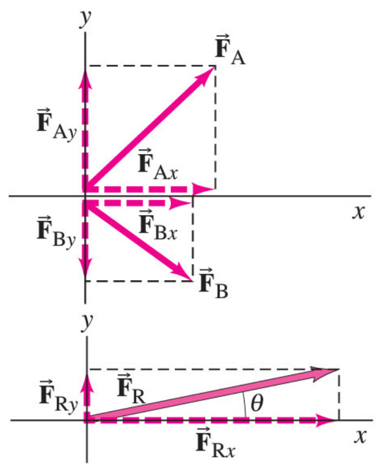
$$F_R = \sqrt{F_{Rx}^2 + F_{Ry}^2} = \sqrt{(52.3)^2 + (10.2)^2}\,\text{N} = 53.3\,\text{N}.$$

The only remaining question is the angle θ that the net force $\vec{\mathbf{F}}_R$ makes with the x axis. We use:

$$\tan\theta = \frac{F_{Ry}}{F_{Rx}} = \frac{10.2\,\text{N}}{52.3\,\text{N}} = 0.195,$$

and $\tan^{-1}(0.195) = 11.0°$. The net force on the boat has magnitude 53.3 N and acts at an 11.0° angle to the x axis.

39



40

ADDITIONAL NOTES

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